SIMPLIFIED DESCRIPTION OF TYPICAL BUILDINGS

- Roof/floor span systems:
- heavy timber rafter roof
 concrete joist and slab
- 3. concrete flat slab

- Wall system:
- 4. interior and exterior concrete bearing walls
- large window penetrations of school and hospital buildings

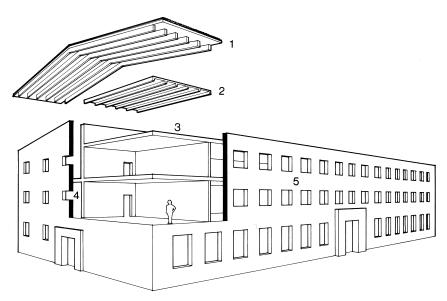


Figure E-30 Drawing of concrete shear-wall building.

E.8.2 Typical Types of Earthquake Damage

This building type generally performs better than concrete frame buildings. The buildings are heavy compared with steel frame buildings, but they are also stiff due to the presence of the shear walls. Damage commonly observed in taller buildings is caused by vertical discontinuities, pounding, and irregular configuration. Other damage specific to this building type includes the following.

- 1. During large seismic events, shear cracking and distress can occur around openings in concrete shear walls and in spandrel beams and link beams between shear walls (See Figures E-31 and E-32.)
- 2. Shear failure can occur at wall construction joints usually at a load level below the expected capacity.
- 3. Bending failures can result from insufficient vertical chord steel and insufficient lap lengths at the ends of the walls.

E.8.3 Common Rehabilitation

Reinforced concrete shear-wall buildings can be rehabilitated in a variety of ways. Techniques

include: (1) reinforcing existing walls in shear by applying a layer of shotcrete or poured concrete; (2) where feasible, filling existing window or door openings with concrete to add shear strength and eliminate critical bending stresses at the edge of openings; and (3) reinforcing narrow overstressed shear panels in in-plane bending by adding reinforced boundary elements (ATC, 1992).

E.9 Concrete Frame with Unreinforced Masonry Infill (C3)

E.9.1 Characteristics

These buildings (Figures E-33 and E-34) have been, and continue to be, built in regions where unreinforced masonry (URM) has not been eliminated by code. These buildings were generally built before 1940 in high-seismicity regions and may continue to be built in other regions.

The first step in identification is to determine if the structure is old enough to contain URM. In contrast to steel frames with URM infill, concrete frames with URM infill usually show clear evidence of the concrete frames. This is particularly true for industrial buildings and can usually be observed at the side or rear of commercial buildings. The concrete col-



Figure E-31 Tall concrete shear-wall building: walls connected by damaged spandrel beams.



Figure E-32 Shear-wall damage, 1989 Loma Prieta earthquake.

umns and beams are relatively large and are usually not covered by masonry but left exposed.

A case in which URM infill cannot be readily identified is the commercial building with large windows on all sides; these buildings may have interior URM partitions. Another difficult case occurs when the exterior walls are covered by decorative tile or

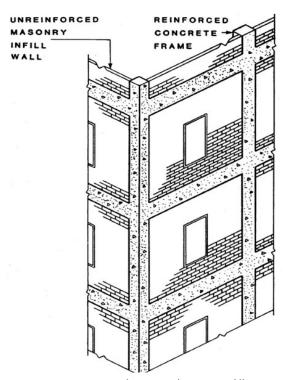


Figure E-33 Concrete frame with URM infill.





Figure E-34 Blow-up (lower photo) of distant view of C3 building (upper photo) showing concrete frame with URM infill (left wall), and face brick (right wall).

stone veneer. The infill material can be URM or a thin concrete infill

E.9.2 Typical Earthquake Damage

The hazards of these buildings, which in the western United States are often older, are similar to and perhaps more severe than those of the newer concrete frames. Where URM infill is present, a falling hazard exists. The failure mechanisms of URM infill in a concrete frame are generally the same as URM infill in a steel frame.

E.9.3 Common Rehabilitation Techniques

Rehabilitation of unreinforced masonry infill in a concrete frame is identical to that of the URM infill in a steel frame. See Section E.6.3. Anchorage of the wall panels for out-of-plane forces is the key component, followed by providing sufficient shear strength in the building.

E.10 Tilt-up Structures (PC1)

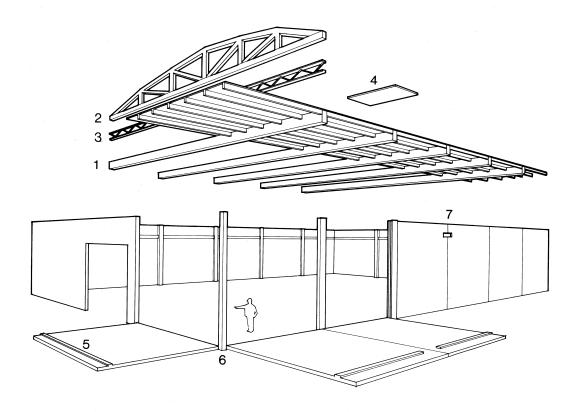
E.10.1 Characteristics

In traditional tilt-up buildings (Figures E-35 through E-37), concrete wall panels are cast on the ground

Roof/floor diaphragms:

4. plywood sheathing

- Roof/floor span systems:
- glue liminated beam and joist
 wood truss
- 3. light steel -web joist



Details:

anchor bolted wooden ledger for roof/floor support Wall systems:

- cast-in-place columns-square, "T" shape, and "H" shape
- 7. welded steel plate type panel connection

Figure E-35 Drawing of tilt-up construction typical of the western United States. Tilt-up construction in the eastern United States may incorporate a steel frame.



Figure E-36 Tilt-up industrial building, 1970s.



Figure E-37 Tilt-up industrial building, mid- to late 1980s.

and then tilted upward into their final positions. More recently, wall panels are fabricated off-site and trucked to the site.

Tilt-up buildings are an inexpensive form of light industrial and commercial construction and have become increasingly popular in the western and central United States since the 1940s. They are typically one and sometimes two stories high and basically have a simple rectangular plan. The walls are the lateral-force-resisting system. The roof can be a plywood diaphragm carried on wood purlins and gluelaminated (glulam) wood beams or a light steel deck and joist system, supported in the interior of the building on steel pipe columns. The wall panels are attached to concrete cast-in-place pilasters or to steel columns, or the joint is simply closed with a later concrete pour. These joints are typically spaced about 20 feet apart.

The major defect in existing tilt-ups is a lack of positive anchorage between wall and diaphragm, which has been corrected since about 1973 in the western United States.

In the western United States, it can be assumed that all one-story concrete industrial warehouses with

flat roofs built after 1950 are tilt-ups unless supplementary information indicates otherwise.

E.10.2 Typical Earthquake Damage

Before 1973 in the western United States, many tiltup buildings did not have sufficiently strong connections or anchors between the walls and the roof and floor diaphragms. The anchorage typically was nothing more than the nailing of the plywood roof sheathing to the wood ledgers supporting the framing.

During an earthquake, the weak anchorage broke the ledgers, resulting in the panels falling and the supported framing to collapse. When mechanical anchors were used they pulled out of the walls or split the wood members to which they were attached, causing the floors or roofs to collapse. See Figures E-38 and E-39. The connections between the concrete panels are also vulnerable to failure. Without these connections, the building loses much of its lateral-force-resisting capacity. For these reasons, many tilt-up buildings were damaged in the 1971 San



Figure E-38 Tilt-up construction anchorage failure.



Figure E-39 Result of failure of the roof beam anchorage to the wall in tilt-up building.

Fernando, California, earthquake. Since 1973, tilt-up construction practices have changed in California and other high-seismicity regions, requiring positive wall-diaphragm connection. (Such requirements may not have yet been made in other regions of the country.) However, a large number of these older, pre-1970s-vintage tilt-up buildings still exist and have not been rehabilitated to correct this wall-anchor defect. Damage to these buildings was observed again in the 1987 Whittier, California, earthquake, 1989 Loma Prieta, California earthquake, and the 1994 Northridge, California, earthquake. These buildings are a prime source of seismic hazard.

In areas of low or moderate seismicity, inadequate wall anchor details continue to be used. Severe ground shaking in such an area may produce major damage in tilt-up buildings.

E.10.3 Common Rehabilitation Techniques

The rehabilitation of tilt-up buildings is relatively easy and inexpensive. The most common form of rehabilitation is to provide a positive anchorage connection at the roof and wall intersection. This is usually done by using pre-fabricated metal hardware attached to the framing member and to a bolt that is installed through the wall. On the outside of the wall a large washer plate is used. See Figure E-40 for examples of new anchors.

Accompanying the anchorage rehabilitation is the addition of ties across the building to develop the anchorage forces from the wall panels fully into the diaphragm. This is accomplished by interconnecting framing members from one side of the building to the other, and then increasing the connections of the diaphragm (usually wood) to develop the additional forces.

E.11 Precast Concrete Frame (PC2)

E.11.1 Characteristics

Precast concrete frame construction, first developed in the 1930s, was not widely used until the 1960s. The precast frame (Figure E-41) is essentially a post and beam system in concrete where columns, beams and slabs are prefabricated and assembled on site. Various types of members are used. Vertical-load-carrying elements may be Ts, cross shapes, or arches and are often more than one story in height. Beams are often Ts and double Ts, or rectangular sections. Prestressing of the members, including pretensioning and post-tensioning, is often employed. The identification of this structure type cannot rely solely on construction date, although most precast concrete





Figure E-40 Newly installed anchorage of roof beam to wall in tilt-up building.

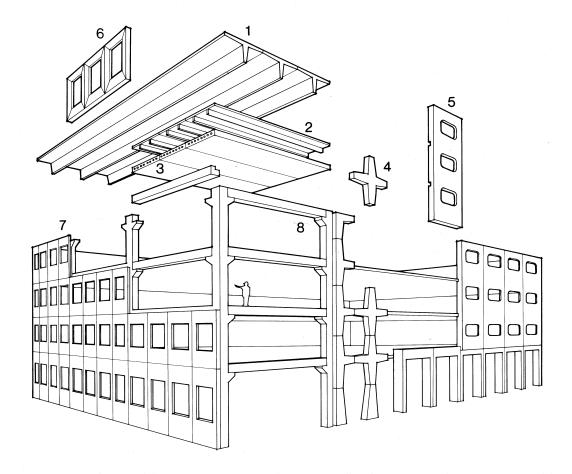
frame structures were constructed after 1960. Some typical characteristics are the following.

- 1. Precast concrete, in general, is of a higher quality and precision compared to cast-in-place concrete. It is also available in a greater range of textures and finishes. Many newer concrete and steel buildings have precast concrete panels and column covers as an exterior finish (See Figure E-42). Thus, the presence of precast concrete does not necessarily mean that it is a precast concrete frame.
- 2. Precast concrete frames are, in essence, post and beam construction in concrete. Therefore, when a concrete structure displays the features of a post-and-beam system, it is most likely that it is a precast concrete frame. It is usually not economical for a conventional cast-in-place concrete frame to look like a post-and-beam system. Features of a precast concrete post-and-beam system include:
- exposed ends of beams and girders that project beyond their supports or project away from the building surface,

- 1. structural concrete "T" sections
- 2. structural double "T" sections
- 3. hollow core concrete slab

Wall systems:

- 4. load-bearing frame components (cross)
- 5. multi-story load-bearing panels



Curtain wall system:

- 6. precast concrete panels
- 7. metal, glass, or stone panels

Structural system:

8. precast column and beams

Figure E-41 Drawing of precast concrete frame building.

- b. the absence of small joists, and
- c. beams sitting on top of girders rather than meeting at a monolithic joint (see Figure E-43)

The presence of precast structural components is usually a good indication of this system, although these components are also used in mixed construction. Precast structural components come in a variety of shapes and sizes. The most common types are sometimes difficult to detect from the street. Less common but more obvious examples include the following.

a. Ts or double Ts—These are deep beams with thin webs and flanges and with large span capacities.

(Figure E-44 shows one end of a double-T beam as it is lowered onto its seat.)

- b. Cross or T-shaped units of partial columns and beams — These are structural units for constructing moment-resisting frames. They are usually joined together by field welding of steel connectors cast into the concrete. Joints should be clearly visible at the mid-span of the beams or the mid-height of the columns. See Figure E-45.
- c. Precast arches—Precast arches and pedestals are popular in the architecture of these buildings.
- d. Column—When a column displays a precast finish without an indication that it has a cover (i.e.,

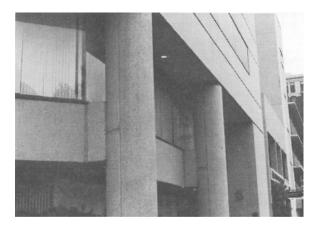


Figure E-42 Typical precast column cover on a steel or concrete moment frame.

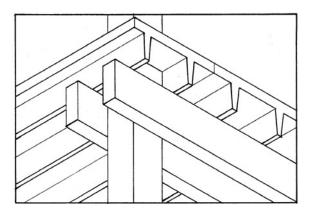


Figure E-43 Exposed precast double-T sections and overlapping beams are indicative of precast frames.



Figure E-44 Example of precast double-T section during installation.

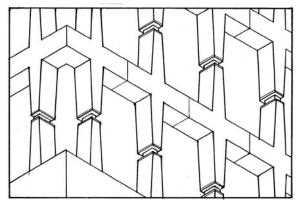


Figure E-45 Precast structural cross; installation joints are at sections where bending is minimum during high seismic demand.

no vertical seam can be found), the column is likely to be a precast structural column.

It is possible that a precast concrete frame may not show any of the above features, however.

E.11.2 Typical Earthquake Damage

The earthquake performance of this structural type varies widely and is sometimes poor. This type of building can perform well if the detailing used to connect the structural elements have sufficient strength and ductility (toughness). Because structures of this type often employ cast-in-place concrete or reinforced masonry (brick or block) shear walls for lateral-load resistance, they experience the same types of damage as other shear-wall building types. Some of the problem areas specific to precast frames are listed below.

- 1. Poorly designed connections between prefabricated elements can fail.
- Accumulated stresses can result due to shrinkage and creep and due to stresses incurred in transportation.
- 3. Loss of vertical support can occur due to inadequate bearing area and insufficient connection between floor elements and columns.
- 4. Corrosion of the metal connectors between prefabricated elements can occur.

E.11.3 Common Rehabilitation Techniques

Seismic rehabilitation techniques for precast concrete frame buildings are varied, depending on the elements being strengthened. Inadequate shear capacity of floor diaphragms can be addressed by adding reinforced concrete topping to an untopped system when possible, or adding new shear walls to reduce the seismic shear forces in the diaphragm. Corbels with inadequate vertical shear or bending strength can be strengthened by adding epoxied horizontal shear dowels through the corbel and into the column. Alternatively, vertical shear capacity can be increased by adding a structural steel bolster under the corbel, bolted to the column, or a new steel column or reinforced concrete column can be added (ATC, 1992).

E.12 Reinforced Masonry (RM1 and RM2)

E.12.1 Characteristics

Reinforced masonry buildings are mostly low-rise structures with perimeter bearing walls, often with wood diaphragms (RM1 buildings) although precast concrete is sometimes used (RM2 buildings). Floor and roof assemblies usually consist of timber joists and beams, glued-laminated beams, or light steel joists. The bearing walls consist of grouted and reinforced hollow or solid masonry units. Interior supports, if any, are often wood or steel columns, wood stud frames, or masonry walls. Occupancy varies from small commercial buildings to residential and industrial buildings. Generally, they are less than five stories in height although many taller masonry buildings exist. Reinforced masonry structures are usually basically rectangular structures (See Figure E-46).



Figure E-46 Modern reinforced brick masonry.

To identify reinforced masonry, one must determine separately if the building is masonry and if it is reinforced. To obtain information on how to recognize a masonry structure, see Appendix D, which describes the characteristics of construction materials. The best way of assessing the reinforcement condition is to compare the date of construction with the date of code requirement for the reinforcement of masonry in the local jurisdiction.

The screener also needs to determine if the building is veneered with masonry or is a masonry building. Wood siding is seldom applied over masonry. If the front facade appears to be reinforced masonry whereas the side has wood siding, it is probably a wood frame that has undergone facade renovation. The back of the building should be checked for signs of the original construction type.

If it can be determined that the bearing walls are constructed of concrete blocks, they may be reinforced. Load-bearing structures using these blocks are probably reinforced if the local code required it. Concrete blocks come in a variety of sizes and textures. The most common size is 8 inches wide by 16 inches long by 8 inches high. Their presence is obvious if the concrete blocks are left as the finish surface.

E.12.2 Typical Earthquake Damage

Reinforced masonry buildings can perform well in moderate earthquakes if they are adequately reinforced and grouted, and if sufficient diaphragm anchorage exists. A major problem is control of the workmanship during construction. Poor construction practice can result in ungrouted and unreinforced walls. Even where construction practice is adequate, insufficient reinforcement in the design can be responsible for heavy damage of the walls. The lack of positive connection of the floor and roof diaphragms to the wall is also a problem.

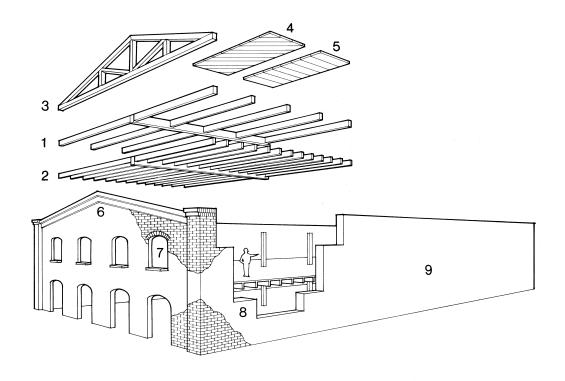
E.12.3 Common Rehabilitation Techniques

Techniques for seismic rehabilitation of reinforced masonry bearing wall buildings are varied, depending on the element being rehabilitated. Techniques for rehabilitating masonry walls include: (1) applying a layer of concrete or shotcrete to the existing walls; (2) adding vertical reinforcing and grouting into ungrouted block walls; and (3) filling in large or critical openings with reinforced concrete or masonry dowelled to the surrounding wall. Wood or steel deck diaphragms in RM1 buildings can be rehabilitated by adding an additional layer of plywood to strengthen and stiffen an existing wood diaphragm, by shear welding between sections of an existing steel deck or adding flat sheet steel reinforcement, or by adding additional vertical elements (for example, shear walls or braced frames) to decrease diaphragm spans and stresses. Precast floor diaphragms in RM2 buildings can be strengthen by adding a layer of concrete topping reinforced with mesh (if the supporting structure has the capacity to carry the additional vertical dead load), or by adding new shear walls to reduce the diaphragm span (ATC, 1992).

- 1. wood post and beam (heavy timber)
- 2. wood post, beam, and joist (mill construction)
- 3. wood truss-- pitch and curve

Roof/floor diaphragms:

- 4. diagonal sheathing
- 5. straight sheathing



Details:

- 6. typical unbraced parapet and cornice
- 7. flat arch window opennings

Wall systems:

- 8. bearing wall-- four or more wythes of brick
- 9. typical long solid party wall

Figure E-47 Drawing of unreinforced masonry bearing-wall building, 2-story.

Unreinforced Masonry (URM) E.13

E.13.1 Characteristics

Most unreinforced masonry (URM) bearing-wall structures in the western United States (Figures E-47 through E-51) were built before 1934, although this construction type was permitted in some jurisdictions having moderate or high seismicity until the late 1940s or early 1950s (in some jurisdictions URM may still be a common type of construction, even today). These buildings usually range from one to six stories in height and function as commercial, residential, or industrial buildings. The construction varies according to the type of use, although wood floor and roof diaphragms are common. Smaller commercial and residential buildings usually have light wood

floor joists and roof joists supported on the typical perimeter URM wall and interior, wood, load-bearing partitions. Larger buildings, such as industrial warehouses, have heavier floors and interior columns, usually of wood. The bearing walls of these industrial buildings tend to be thick, often as much as 24 inches or more at the base. Wall thickness of residential, commercial, and office buildings range from 9 inches at upper floors to 18 inches a lower floors.

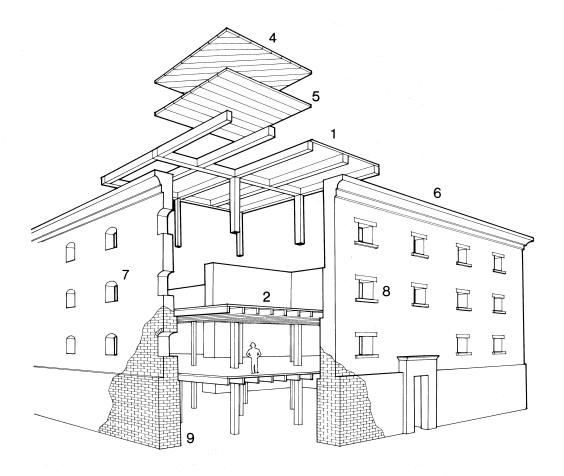
The first step in identifying buildings of this type is to determine if the structure has bearing walls. Second, the screener should determine the approximate age of the building. Some indications of unreinforced masonry are listed below.

Weak mortar was used to bond the masonry units together in much of the early unreinforced

- 1. wood post and beam (heavy timber)
- 2. wood post, beam, and joist (mill construction)
- 3. wood truss-- pitch and curve

Roof/floor diaphragms:

- 4. diagonal sheathing
- 5. straight sheathing



Wall systems:

Details:

- 6. typical unbraced parapet and cornice
- 7. flat arch window opennings
- 8. small window penetrations (if bldg is originally a warehouse)

Figure E-48 Drawing of unreinforced masonry bearing-wall building, 4-story.

masonry construction in the United States. As the poor earthquake performance of this mortar type became known in the 1930s, and as cement mortar became available, this weaker mortar was not used and thus is not found in more recent masonry buildings. If this soft mortar is present, it is probably URM. Soft mortar can be scratched with a hard instrument such as a penknife, screwdriver, or a coin. This scratch testing, if permitted, should be done in a wall area where the original structural material is exposed, such as

the sides or back of a building. Newer masonry may be used in renovations and it may look very much like the old. Older mortar joints can also be repointed (i.e., regular maintenance of the masonry mortar), or repaired with newer mortar during renovation. The original construction may also have used a high-quality mortar. Thus, even if the existence of soft mortar cannot be detected, it may still be URM.

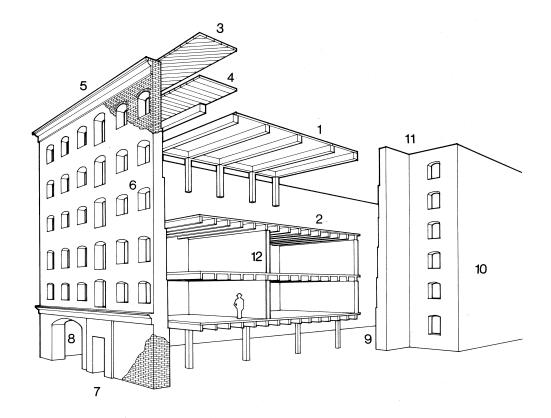
9. bearing wall-- four to eight wythes of brick

2. An architectural characteristic of older brick bearing-wall structures is the arch and flat arch

- 1. wood post and beam (heavy timber)
- 2. wood post, beam, and joist (mill construction)

Roof/floor diaphragms:

- 3. diagonal sheathing
- 4. straight sheathing



Details:

- 5. typical unbraced parapet and cornice
- 6. flat arch window opennings
- 7. typical penetrated facade of residential buildings
- 8. large opennings of ground floor shops

Wall systems:

- 9. bearing wall-- four to eight wythes of brick
- 10. typical long solid party wall
- 11. light/ventilation wells in residential bldg
- 12. non-structural wood stud partition walls

Figure E-49 Drawing of unreinforced masonry bearing-wall building, 6-story.



Figure E-50 East coast URM bearing-wall building.



Figure E-51 West coast URM bearing-wall building.

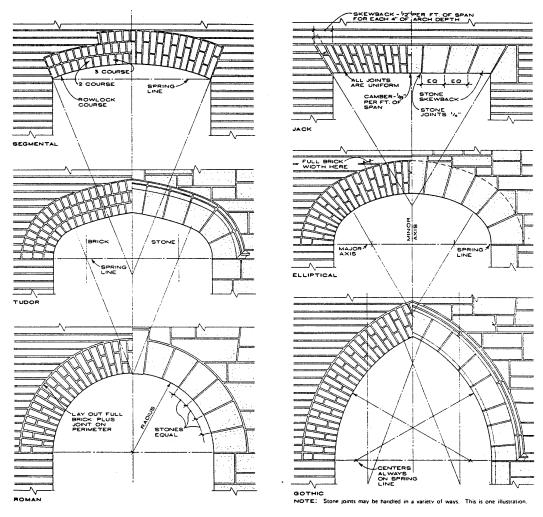


Figure E-52 Drawings of typical window head features in URM bearing-wall buildings.

window heads (see Figure E-52). These arrangements of masonry units function as a header to carry the load above the opening to either side. Although masonry-veneered wood-frame structures may have these features, they are much more widely used in URM bearing-wall structures, as they were the most economical method of spanning over a window opening at the time of construction. Other methods of spanning are also used, including steel and stone lintels, but these methods are generally more costly and usually employed in the front facade only.

3. Some structures of this type will have anchor plates visible at the floor and roof lines, approximately 6-10 feet on center around the perimeter of the building. Anchor plates are usually square or diamond-shaped steel plates approximately 6 inches by 6 inches, with a bolt and nut at the center. Their presence indicates anchor ties have been placed to tie the walls to the floors and roof.

These are either from the original construction or from rehabilitation under local ordinances. Unless the anchors are 6 feet on center or less, they are not considered effective in earthquakes. If they are closely spaced, and appear to be recently installed, it indicates that the building has been rehabilitated. In either case, when these anchors are present all around the building, the original construction is URM bearing wall.

- 4. When a building has many exterior solid walls constructed from hollow clay tile, and no columns of another material can be detected, it is probably not a URM bearing wall but probably a wood or metal frame structure with URM infill.
- One way to distinguish a reinforced masonry building from an unreinforced masonry building is to examine the brick pattern closely. Reinforced masonry usually does not show header bricks in the wall surface.

If a building does not display the above features, or if the exterior is covered by other finish material, the building may still be URM.

E.13.2 Typical Earthquake Damage

Unreinforced masonry structures are recognized as the most hazardous structural type. They have been observed to fail in many modes during past earthquakes. Typical problems include the following.

1. Insufficient Anchorage—Because the walls, parapets, and cornices are not positively anchored to the floors, they tend to fall out. The collapse of bearing walls can lead to major building collapses. Some of these buildings have anchors as a part of the original construction or as a rehabilitation. These older anchors exhibit questionable performance. (See Figure E-53 for parapet damage.)



Figure E-53 Parapet failure leaving an uneven roof line, due to inadequate anchorage, 1989 Loma Prieta earthquake.

2. Excessive Diaphragm Deflection—Because most of the floor diaphragms are constructed of finished wood flooring placed over ³/₄"-thick wood sheathing, they tend to be stiff compared with other types of wood diaphragms. This stiffness results in rotations about a vertical axis,

accompanying translations in the direction of the open front walls of buildings, due to a lack of inplane stiffness in these open fronts. Because there is little resistance in the masonry walls for out-of-plane loading, the walls allow large diaphragm displacements and cause the failure of the walls out of their plane. Large drifts occurring at the roof line can cause a masonry wall to overturn and collapse under its own weight.

3. Low Shear Resistance—The mortar used in these older buildings was often made of lime and sand, with little or no cement, and had very little shear strength. The bearing walls will be heavily damaged and collapse under large loads. (See Figure E-54)



Figure E-54 Damaged URM building, 1992 Big Bear earthquake.

4. Slender Walls —Some of these buildings have tall story heights and thin walls. This condition, especially in non-load-bearing walls, will result in buckling out-of-plane under severe lateral load. Failure of a non-load-bearing wall represents a falling hazard, whereas the collapse of a load-bearing wall will lead to partial or total collapse of the structure.

E.13.3 Common Rehabilitation Techniques

Over the last 10 years or more, jurisdictions in California have required that unreinforced masonry bearing-wall buildings be rehabilitated or demolished. To minimize the economical impact on owners of having to rehabilitate their buildings, many jurisdictions implemented phased programs such that the critical items were dealt with first. The following are the key elements included in a typical rehabilitation program.

1. Roof and floor diaphragms are connected to the walls for both anchorage forces (out of the plane of the wall) and shear forces (in the plane of the

- wall). Anchorage connections are placed at 6 feet spacing or less, depending on the force requirements. Shear connections are usually placed at around 2 feet center to center. Anchors consist of bolts installed through the wall, with 6-inch-square washer plates, and connected to hardware attached to the wood framing. Shear connections usually are bolts embedded in the masonry walls in oversized holes filled with either a non-shrink grout or an epoxy adhesive. See Figure E-55.
- 2. In cases when the height to thickness ratio of the walls exceeds the limits of stability, rehabilitation consists of reducing the spans of the wall to a level that their thickness can support. Parapet rehabilitation consists of reducing the parapet to what is required for fire safety and then bracing from the top to the roof.
- 3. If the building has an open storefront in the first story, resulting in a soft story, part of the storefront is enclosed with new masonry or a steel frame is provided there, with new foundations.
- 4. Walls are rehabilitated by either closing openings with reinforced masonry or with reinforced gunite.





Figure E-55 Upper: Two existing anchors above three new wall anchors at floor line using decorative washer plates. Lower:
Rehabilitation techniques include closely spaced anchors at floor and roof levels.